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RATING ANALYSIS FOR PUMP STATION S13

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Executive Summary

The first hydraulic rating analysis for pump station S13 was completed in 1999 and then reevaluated in 2004. In the first rating analysis, it is believed that the design engine speed was incorrectly set to 1600 rpm while it actually should have been 1200 rpm prior to the 1995 pump station upgrade. Therefore, this rating is suspect. The 2004 rating, on the other hand, was based primarily on eleven available flow measurements. Unfortunately, these measurements included one erroneous measurement along with five others that were not subjected to any formal QA/QC process. The remaining five measurements were comprised of one measurement rated as Good and four rated as Fair. These measurements alone do not form an adequate basis for a rating analysis. Consequently, the 2004 rating is also suspect.

Given these findings, a subsequent rating analysis of S13 was deemed necessary and carried out using the conventional case 8 model and pump performance data. The rating equation developed yields discharges rates that are within 0.60 percent of the discharges derived from the pump station performance curve under the expected range of static heads. Existing flow measurements were used for comparative purposes only.

An impact analysis was carried out and it shows that between January 1, 1984 and March 1, 1995, the differences between the mean daily flows computed with the new and existing rating equations are as high as 52.9 percent. A maximum difference of 16.8 percent is evident between March 1, 1995 and June 15, 2004 while the two sets of discharges agree to within 7.7 percent from June 15, 2004 to the present. One mean daily discharge during this time, however, differed by 53.1 percent.

It is recommended that all flows computed with the previous rating equation be reloaded in DBHydro under a new DBKey. Furthermore, it is recommended that additional discharge measurements of acceptable quality be obtained and used to calibrate the proposed rating equation.

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Introduction

The structure S13 is a combination of a pumping station and a gated spillway. S13 is located in Canal 11(South New River Canal) about 300 feet west of U.S. Highway 441 and 5.5 miles southwest of Fort Lauderdale (Figure 1). The pump station is equipped with three vertical propeller pumps each having a rated capacity of 180 cfs at a 4 ft static head.

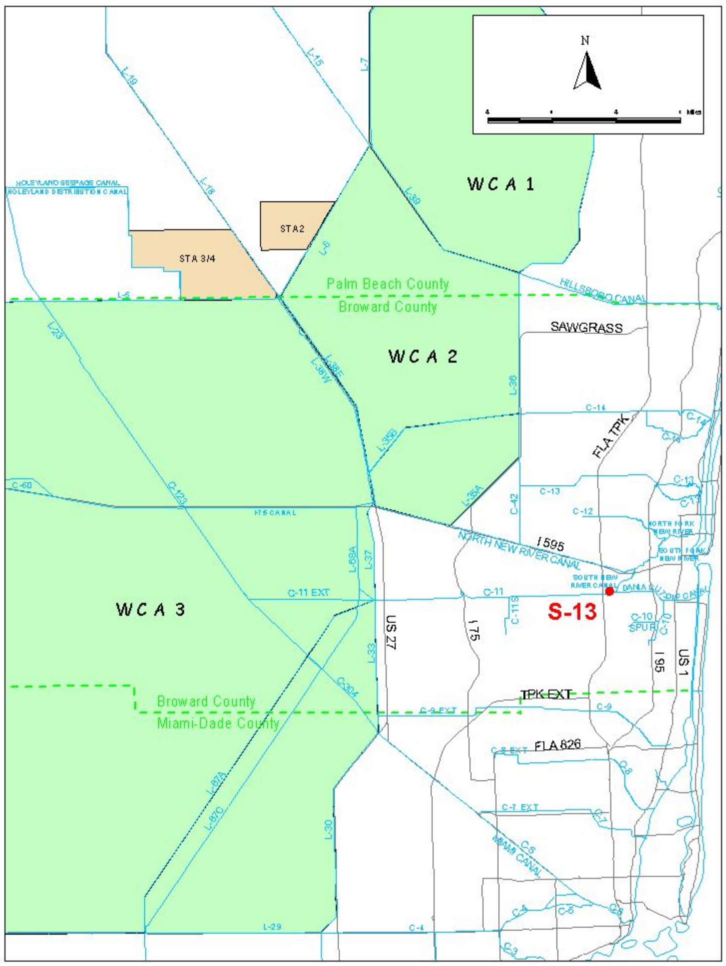

Figure 1. Location map for pump station S13

The purpose of the structure is to release flood runoff from, prevent over drainage of, and prevent salt water intrusion into the agricultural area served by Canal 11 west of the structure. In particular, the pumping units in the structure are used for discharging surplus water from the agricultural area west of the structure. It is intended to keep the water level in the C-11 canal as close as possible to the optimum elevation of 2.2 ft above mean sea level.

Pump operation takes place when the structure’s headwater elevation is over 2.5 ft above mean sea level and the tailwater elevation is less than 8 ft above mean sea level. The headwater elevation varies from 2.2 ft to 2.5 ft and the tailwater elevation varies from 6.2 ft to 6.5 ft. The design discharge for the pumps is 540 cfs (Imru and Wang, 2004).

The annual flow records of structure S13 consist of flows through the spillway and flows through the pumps. The responsibility of flow monitoring through the spillway and pumps is divided between two agencies. Discharge computations through the spillway are carried out by the USGS while the South Florida Water Management District (District) computes flow through the pumps.

Previous Rating Analyses

The first flow rating at this station was presented by Imru (1999). Unfortunately, this report could not be located. It is indicated in DBHydro that the rated engine speed was 1600 rpm prior to March 1, 1995. However, other sources (e.g., the SFWMD structure book, the OMD 2002 Report and Imru and Wang, 2004) specify the rated engine speed as 1200 rpm before the 1995 mechanical modifications were carried out. During the upgrade in 1995, only the engines and the reduction gears were replaced. All the piping was kept intact. Although the same sources indicate that the design engine speed was increased from 1200 to 1625 rpm after the mechanical upgrade, the current engine tag specifies a design engine speed of 1800 rpm for each unit. Also specified is a gear reduction ratio of 9.42, resulting in a rated pump speed of 191 rpm (The actual design speed of the pump from the pump curve available shows that the design pump speed is 190.5 rpm, if multiplied by the gear reduction ratio of 9.42, will result in a design engine speed of 1795 rpm). This matches the design pump speed specified before the 1995 upgrade and confirms the fact that the pump remained unchanged while the engines were replaced. Unless other mechanical modifications occurred between February 1995 and the present, the design engine speeds should be set to 1795.

A subsequent hydraulic analysis for this station was performed by Imru and Wang (2004). They converted the previous rating from a case 7 equation to a case 8 equation using the available discharge measurements. Unfortunately, these measurements included one erroneous measurement along with five others that were not subjected to any formal QA/QC process. The remaining five measurements were comprised of one measurement rated as Good and four rated as Fair. In fact, two of the flow measurements rated Fair had the same engine speed of 1500 rpm and similar static heads (one is 0.5 ft, the other is 0.74 ft) while their discharge values differed by 20 percent. This suggests that these measurements alone do not form an adequate basis for a rating analysis.

Objective and Scope

The objective of this report is to present a new rating analysis for the pumps at S13_P. The current analysis is based on the pump performance curve, hydraulic properties of the station and a case 8 equation. Furthermore, previous errors in design engine speeds will be addressed and an impact analysis will be carried out in order to evaluate the effect of the new rating on the current database.

Station Design

The manufacturer's pump performance curves for all three pumps are shown in Figure 2. As mentioned previously, the pump unit itself was not previously subjected to any mechanical upgrades. Therefore, the pump performance curves are assumed to be valid for the current rating effort. Cross sectional and plan views of the pump station design are shown in figure 3. This figure contains one of the record drawings completed just after the pump station was constructed in 1954.

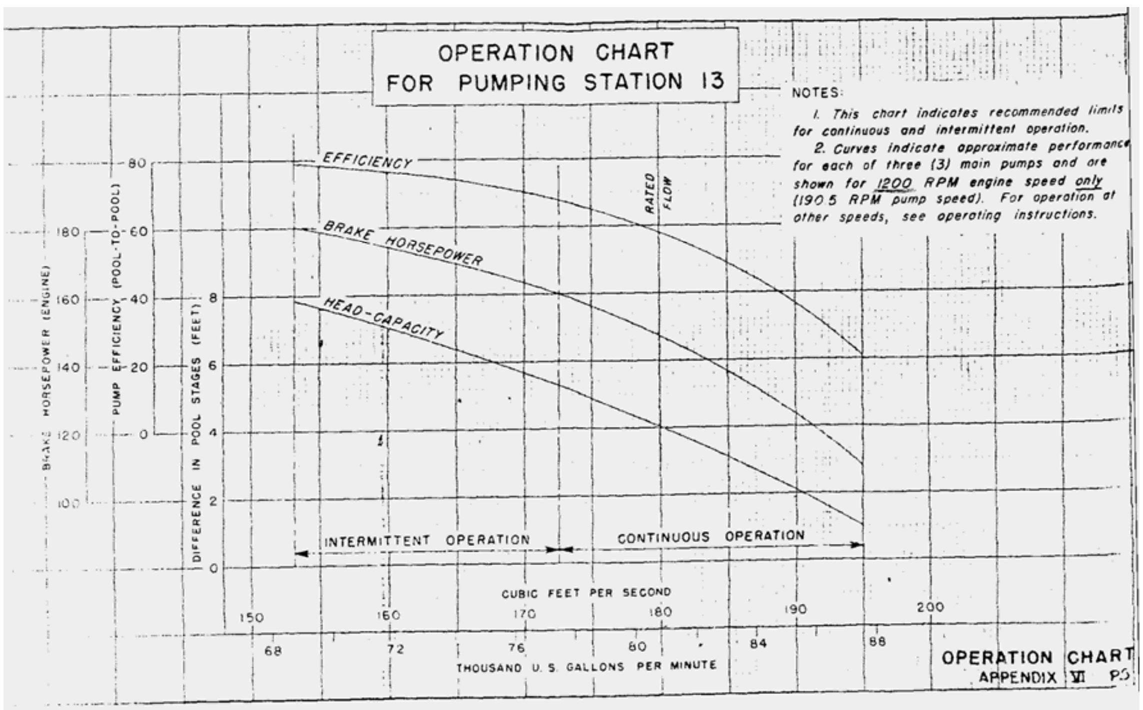

Figure 2. Pump performance curve for station S13.

The dimensions of the station piping are shown in table 1 while table 2 lists the appurtenances located between each pump and the discharge outlet. Listed also are the head loss coefficients. Table 3 contains estimates of pipe roughness for steel pipes.

Figure 3. Plan and section views of S13_P.

Table 1. Dimensions of the station piping at S13_P.

Steel Pipe Dimensions at S13			
Pipe OD =	80.6	in	*plans*
Wall Thickness =	0.500	in	*assumed based on project plans and standards*
Pipe ID =	77	in	
Pipe ID =	6.417	ft	
Pipe Length =	15.0	ft	*project plans*
Area =	32.34	sq ft	
Cement Mortar Lining	0	in	

Table 2. Losses of appurtenances located between each pump and the discharge outlet.

Local Losses				
Number	**K**	**min**	**max**	**sources**
1	$K_{expansion}$ =	0.012	0.012	*Sanks (1989)*
1	K_{elb} =	0.14	0.23	*Sanks (1989)*
1	K_{ext} =	1.00	1.00	*Sanks (1989)*
	ΣK_m =	1.15	1.24	
	$\Sigma K_{m\ (Avg)}$ =	1.20		

Table 3. Estimates of pipe roughness for steel pipes.

Pipe Head Losses				
ε =	0.00015	ft	*Hydraulic Inst.*	new steel
ε =	0.00133	ft	*Sanks (1989)*	old steel

Rating Analysis

The model rating equation applied to S13_P is the standard case 8 model (Imru and Wang, 2004):

$$Q = A\left(\frac{N}{N_O}\right) + BH^C\left(\frac{N_O}{N}\right)^{2C-1} \quad \text{.......................................} (1)$$

Where Q is the discharge at N RPM, H is the TSH, N_O is the design engine or pump speed, and A, B and C are coefficients to be determined through regression. The form of this expression was determined through dimensional analysis and is based on the pump affinity laws.

Figure 4 depicts the TSH vs. flow relationship obtained from the pump performance curve while assuming minimum, average and maximum head losses within the discharge conduit. For comparison, the TDH vs. flow relationship is also shown. It is evident from Figure 4 that the difference between the minimum, average and maximum head losses is negligible. Also presented in Figure 4 are the rating curves for various engine speeds and all available flow measurements. The data points are color-coded to indicate their associated engine speeds. Equation (1) was fit to the average TSH vs. Q curve shown in Figure 4. The resultant values of A, B and C are provided in table 4. Tables 5 provide a comparison of the rating equation with the pump station performance curve. The associated head loss computations are provided in appendix A.

Table 4. Regression parameters for S13_P.

Regression Parameter for Equation (1)	A	B	C
Approximate lower 95% C.I.	194.10	-3.8850	1.1750
Estimate	195.40	-3.1067	1.2936
Approximate upper 95% C.I.	196.80	-2.3284	1.4122

Impact Analysis

An impact analysis was carried out by first inputting all the new regression constants into the Hydroedit database under the development environment and then using the flow program in the production environment to calculate the flows for the new rating. The calculated discharges were compared with the corresponding discharges computed from the existing regression equation. The impacts of the new rating constants can be described as follows. Between January 1, 1984 and March 1, 1995, the differences between the mean daily flows computed with the new and existing rating equations are as high as 52.9 percent. A maximum difference of 16.8 percent is evident between March 1, 1995 and June 15, 2004 while the two sets of discharges agree to within 7.7 percent from

June 15, 2004 to the present. One mean daily discharge during this time, however, differed by 53.1 percent. The annual average differences between flows computed using existing and current rating equations are tabulated in Table 6.

Table 5. Comparison of the regression equation and pump station performance curve.

TSH	Q (p.s. perf. curve)	Q (regression)	%Error
7.22	155.00	155.34	0.22
6.64	160.00	159.42	-0.36
5.98	165.00	164.01	-0.60
5.20	170.00	169.19	-0.48
4.36	175.00	174.51	-0.28
3.48	180.00	179.78	-0.12
2.56	185.00	184.94	-0.03
1.53	190.00	190.03	0.02
0.45	195.00	194.31	-0.35

Table 6. Annual average difference between flows computed using existing and current rating equations.

Year	Annual Average Difference (%)
1984	45.1
1985	50.6
1986	48.4
1987	46.9
1988	46.6
1989	38.7
1990	48.6
1991	48
1992	48.9
1993	50.3
1994	16.3
1995	3.8
1996	3.3
1997	5.7
1998	7
1999	3.4
2000	6.8
2001	6.3
2002	2.4
2003	4.3
2004	3.2
2005	3
2006	1.9
Total	539.5
Average	23.5

Stream-Gauging Needs

There are eighteen (18) stream flow measurements available for this station in the stream gauging database Qmeas. The available measurements can be divided into two groups based on the time of the station upgrade. Group 1 includes five measurements based on a design engine speed of 1200 rpm and Group 2 includes thirteen measurements that reflect a design engine speed of 1795 rpm. Group 1 includes one bad measurement and four good measurements per Qmeas quality standards. All five measurements were obtained from Price AA meter. Group 2 includes 13 data points with two tagged “Bad”, five tagged “Not Processed”, four judged to be “Fair” and two judged to be “Good”. Furthermore, both sets of measurements were obtained within small total static head range of 0 to 2 ft. For rating purposes, measurements reflecting static heads outside of the range are needed. Furthermore, since it is possible that this pump station will be operated while the headwater is higher than tailwater, flow measurements should be obtained under this condition. Currently, there is only one such measurement available.

The stream-gauging data needs for pump station S13 are summarized in Table 6. Indicated is the targeted number of flow measurements under each of the operating conditions.

Table 7. Stream-gauging needs for S13_P.

	No. of Measurements Needed	Engine Speed (rpm)		
	TSH (ft)	650~1067	1067~1433	1433~1800
S13_P Diesel Pump Unit 1,2,3	0~2.0	5	5	5
	2.0~4.0	5	5	5
	4.0~6.0	5	5	5

Summary and Conclusions

A rating analysis of S13 pump station was carried out using the conventional case 8 model and the manufacturer pump performance curve. A rating equation was developed for three identical pump units configured the same way. The equation yields discharge rates that are within 0.60% of the discharges derived from the pump performance curve under the expected range of static heads. Furthermore, it is recommended that the rating equation be recalibrated with more measured flows that have better quality than the ones currently available.

It is recommended that all flows computed with the previous rating equation be reloaded in DBHydro. Given the uncertainties inherent to the hydraulic head loss calculations performed in the current analysis, it is recommended that additional discharge measurements of acceptable quality be obtained and used to calibrate the proposed rating equation.

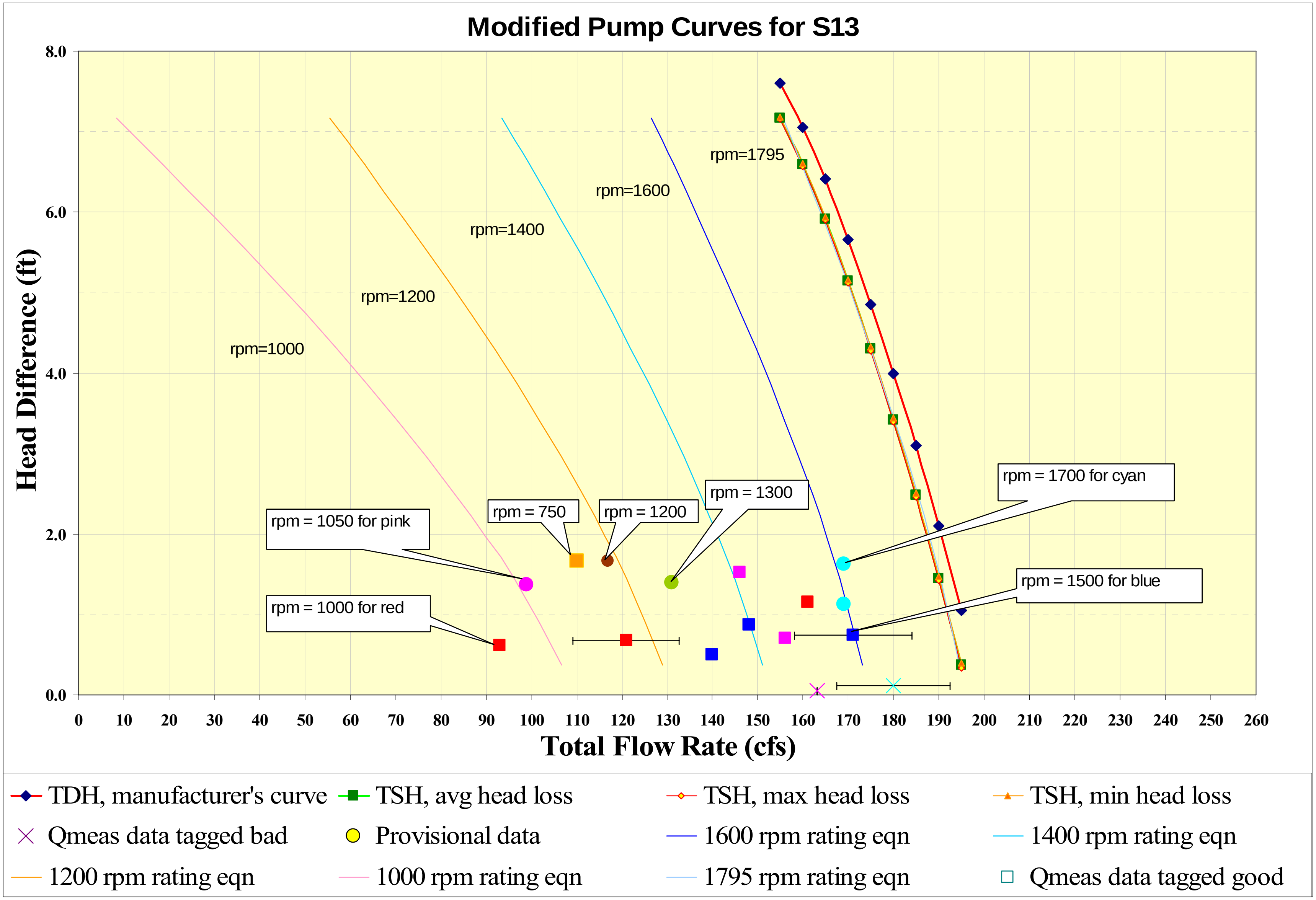

Figure 4. Pump curve, TSHs, rating curves and flow measurements at pump station S13.

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Appendix: Head loss calculations

Minimum head loss calcuations

1795 RPM			Swamee & Jain(1976)							
TDH(ft)	Q (GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
7.60		155.00	4.49	2975158	0.31	0.01070	0.01	0.36	0.37	7.23
7.05		160.00	4.63	3071131	0.33	0.01067	0.01	0.38	0.39	6.66
6.41		165.00	4.77	3167103	0.35	0.01064	0.01	0.41	0.42	5.99
5.66		170.00	4.92	3263076	0.38	0.01061	0.01	0.43	0.44	5.22
4.85		175.00	5.06	3359049	0.40	0.01058	0.01	0.46	0.47	4.38
4.00		180.00	5.21	3455022	0.42	0.01056	0.01	0.49	0.50	3.50
3.10		185.00	5.35	3550995	0.44	0.01053	0.01	0.51	0.52	2.58
2.10		190.00	5.50	3646968	0.47	0.01051	0.01	0.54	0.55	1.55
1.05		195.00	5.64	3742940	0.49	0.01048	0.01	0.57	0.58	0.47

Average head loss calcuations

1795 RPM			$f_{av} = sqrt(f_{min}f_{max})$						
TDH(ft)	Q (GPM)	Q(cfs)	V(ft/s)	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
7.60		155.00	4.49	0.31	0.01231	0.01	0.37	0.38	7.22
7.05		160.00	4.63	0.33	0.01229	0.01	0.40	0.41	6.64
6.41		165.00	4.77	0.35	0.01226	0.01	0.42	0.43	5.98
5.66		170.00	4.92	0.38	0.01224	0.01	0.45	0.46	5.20
4.85		175.00	5.06	0.40	0.01222	0.01	0.48	0.49	4.36
4.00		180.00	5.21	0.42	0.01220	0.01	0.50	0.52	3.48
3.10		185.00	5.35	0.44	0.01218	0.01	0.53	0.54	2.56
2.10		190.00	5.50	0.47	0.01217	0.01	0.56	0.57	1.53
1.05		195.00	5.64	0.49	0.01215	0.01	0.59	0.60	0.45

Maximum head loss calculations

1795 RPM			Swamee & Jain(1976)								
TDH(ft)	**Q (GPM)**	**Q(cfs)**	**V(ft/s)**	**N_R**	**$V^2/2g$ (ft)**	**f**	**$h_l = f(L/D)V^2/2g$**	**$h_m = \Sigma KV^2/2g$**	**Total Head Loss (ft)**	**Static Head (ft)**	
7.60		155.00	4.49	2975158	0.31	0.01416	0.01	0.39	0.40	7.20	
7.05		160.00	4.63	3071131	0.33	0.01415	0.01	0.41	0.42	6.63	
6.41		165.00	4.77	3167103	0.35	0.01413	0.01	0.44	0.45	5.96	
5.66		170.00	4.92	3263076	0.38	0.01412	0.01	0.47	0.48	5.18	
4.85		175.00	5.06	3359049	0.40	0.01411	0.01	0.49	0.51	4.34	
4.00		180.00	5.21	3455022	0.42	0.01411	0.01	0.52	0.54	3.46	
3.10		185.00	5.35	3550995	0.44	0.01410	0.01	0.55	0.57	2.53	
2.10		190.00	5.50	3646968	0.47	0.01409	0.01	0.58	0.60	1.50	
1.05		195.00	5.64	3742940	0.49	0.01408	0.02	0.61	0.63	0.42	